المدرسة المحمدية للمهندسين

Ecole Mohammadia d'Ingénieurs

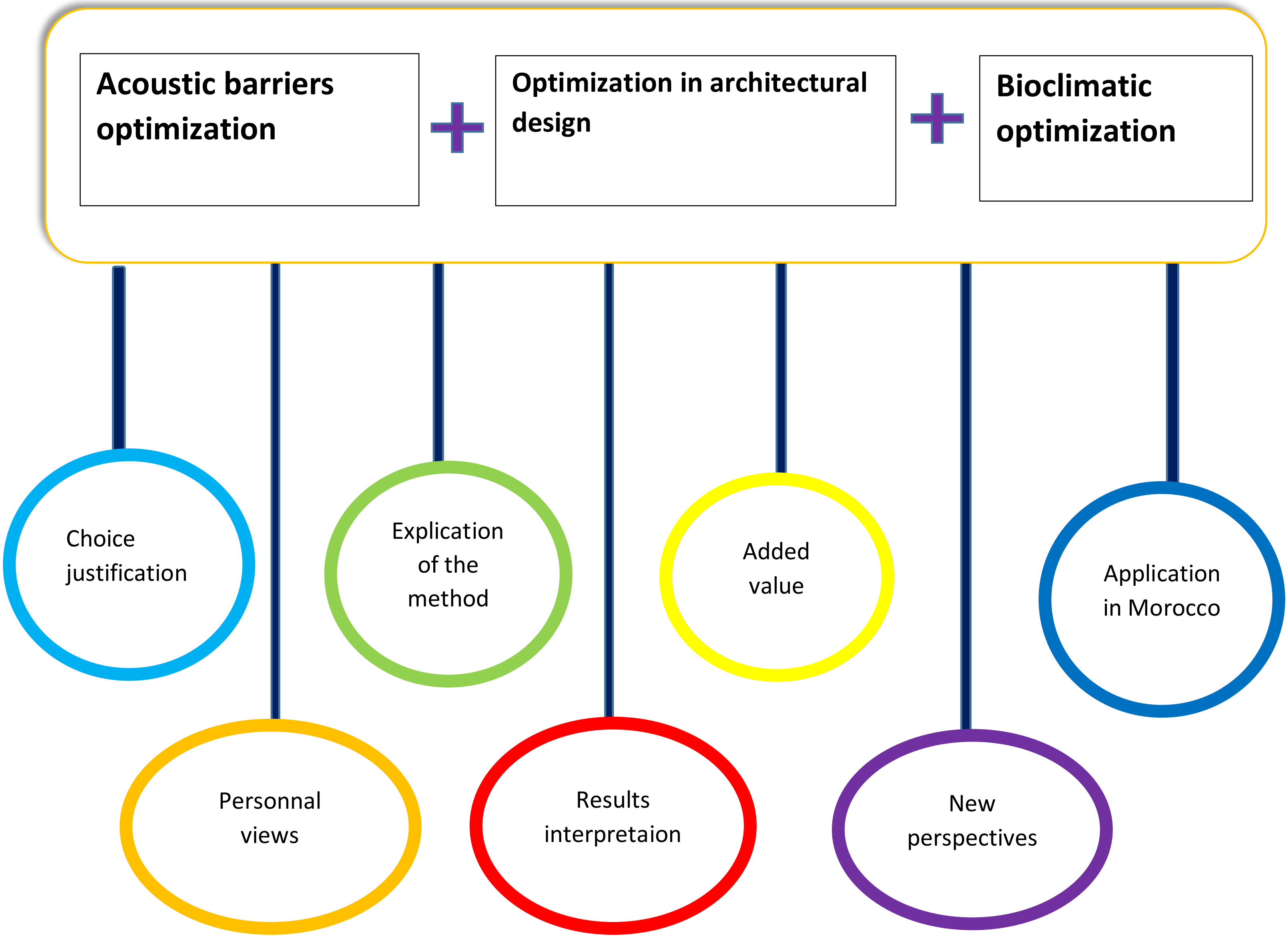
Optimization in civil engineering

Realized by: IGUIR YOUSSEF Naima

Supervisor: Mrs ELMKHALET Mouna

What this report is about :

Civil Engineering:



Acoustic barriers optimization + **Optimization in architectural design** + **Bioclimatic optimization**

Choice justification

Personnal views

Explication of the method

Results interpretaion

Added value

New perspectives

Application in Morocco

Introduction :

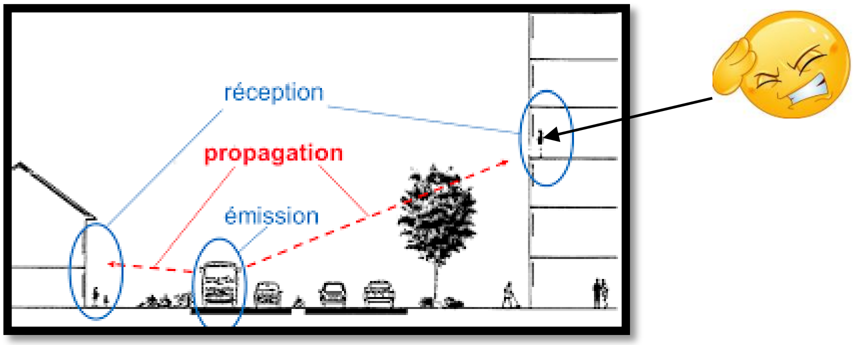
The world is experiencing a continuous and growing trend of integrating optimization techniques into the implementation of projects in different fields. In addition to identifying the problems encountered and developing a resolution plan, it is now very substantial to be able to design techniques to optimize these solutions, which means minimizing the effect of any agent that may generate significant losses and maximize any function from which we can profit, whether they are economic or environmental benefits.

Civil engineering is one of the fields that requires the application of optimization methods in the development of public works, building or VRD projects ... because it requires large quantities of materials of different types, space, time and energy, so many functions to be optimized in order to properly manage and preserve natural resources and create design structures that are sometimes popularized as “crazy” given their unusual shape and morphology resulting from methods and algorithms optimization. In this report, I present some examples of applications of optimization in this area as well as the methods frequently used to solve either architectural or structural problems encountered.

Acoustic barriers

Choice justification:

Personally, I am very sensitive to the noise of the streets generated by the car horn, the sound of the engines, the braking, ... I close the windows to reduce the sound entering my room but the sound waves still manage to pass through the walls, and it's really stressful. When I decided to follow the career of a civil engineer, I had the idea of building my own house designed by myself in such a way that it was equipped with sound insulation at a high level and that was the reason why I started to be interested in sound insulation, in particular all the advancements in terms of materials or techniques.



And recently, while reading a scientific article in the magazine "Futura sciences", I found that among the methods that have been proposed by acousticians, there is the construction of noise barriers along roadways to protect all buildings from road noise. And in this sense, works to optimize the parameters of these barriers have been carried out in order to improve their effectiveness, I have chosen to talk about them in details in this part.

Before starting calculations:

- Improving the sound insulation of a wall consists of studying several parameters, including the shape of the walls, their sizes, the type of materials used and their multiple characteristics. But since the integration of these last parameters requires a really complex study, I am limited in this work to the study of the most optimal form without taking into consideration the components of these walls.
- It is well known that the position and height of the barrier are important parameters of its effectiveness. So, it is possible to increase the attenuation, by building a wall of higher height. However, for practical or esthetic reasons, it is generally not desirable to have walls that are too high. It is therefore useful to try to optimize the efficiency of a wall for a given maximum height.

The method used in this subject:

The algorithm used is: the genetic algorithm.

A genetic algorithm is an evolutionary algorithm that is part of metaheuristic algorithms. It is a method of solving optimization problems, with or without constraints, based on a process of natural selection (a process analogous to biological evolution). In such an algorithm, a population of solutions is modified several times. Each time, the algorithm randomly selects individuals from the population and uses them as parents to produce the children of the next generation. Over successive generations, the population "evolves" towards an optimal solution.

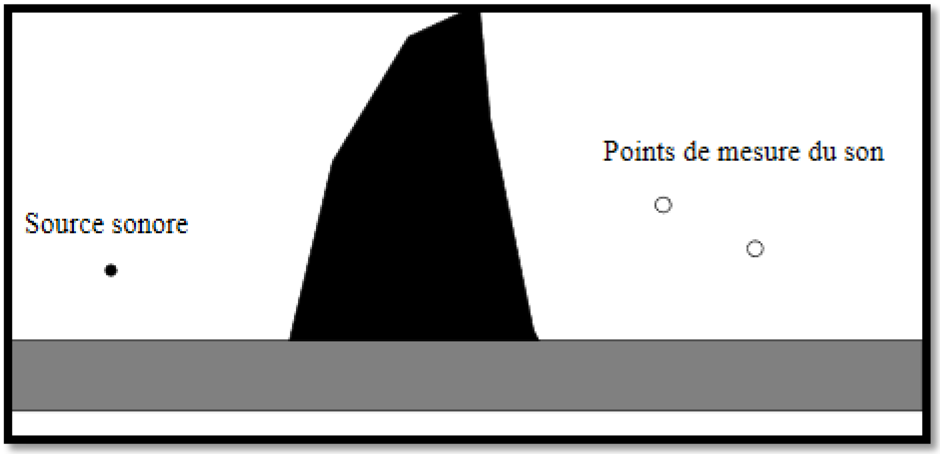
They have three main genetic operators: crossover, mutation, and selection.

- **Crossover***:* Swapping parts of the solution with another in chromosomes or solution representations. The main role is to provide mixing of the solutions and convergence in a subspace.
- **Mutation***:* The change of parts of one solution randomly, which increases the diversity of the population and provides a mechanism for escaping from a local optimum.
- **Selection of the fittest, or elitism**: The use of the solutions with high fitness to pass on to next generations, which is often carried out in terms of some form of selection of the best solutions.

Calculations:

Calculation of the pressure field:

The studied problem is described in the following figure which presents a wall of arbitrary shape:



It is considered that the propagation of the sound is normal to the wall, for this reason the system is only modeled in 2D.

There is a sound source emitting noise on one side of the wall, and we are interested in the noise level on the other side in order to minimize it. To simplify the study and to highlight the influence of the shape we will make the following assumptions:

- the wall and floor surfaces are rigid
- The pressure field will be assumed to be harmonic with a time dependence of the type e (−iωt) and it is therefore a solution of the following Helmholtz equation:

$$\Delta p(x, \omega) + k \hat{} 2 \ * \ p(x, \omega) = s(x, \omega)$$

With

- **p** is the pressure at point x and at frequency ω.
- **k=w/c** is the wave number, "c" is the speed of sound, and s (x, ω) is the source term in air.

- As the barrier and the ground are rigid, the pressure field must verify the following condition on both surfaces: $\partial p/\partial n = 0$.

  In addition the pressure field must satisfy the radiation condition at infinity which is written in the following form:

$$\lim_{r\to\infty}\left(\frac{\partial p}{\partial r} - ikp\right) = 0\left(\frac{1}{\sqrt{r}}\right)$$

◆ **Goal:** minimization of the sound behind the barrier using the following objective function:

$$J = 10\log_{10}\left[\frac{1}{n_p n_f}\sum_{i=1}^{n_f}\sum_{j=1}^{n_p}|p(x_j,\omega_i)|^2/4.10^{-10}\right]$$

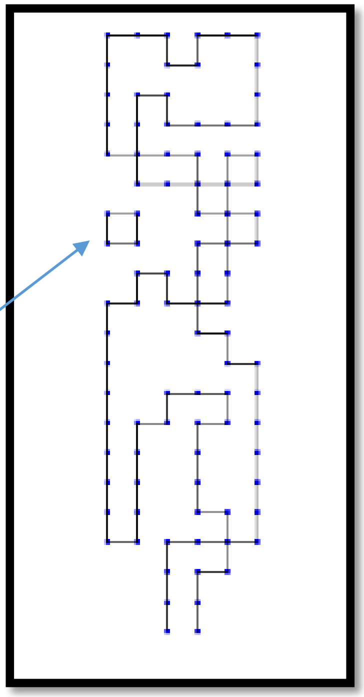
Np : checkpoints and **nf** : number of frequencies.

Results:

The most optimal shape of the wall is of the following shape:

How can we build a wall like this?

I'm getting confused



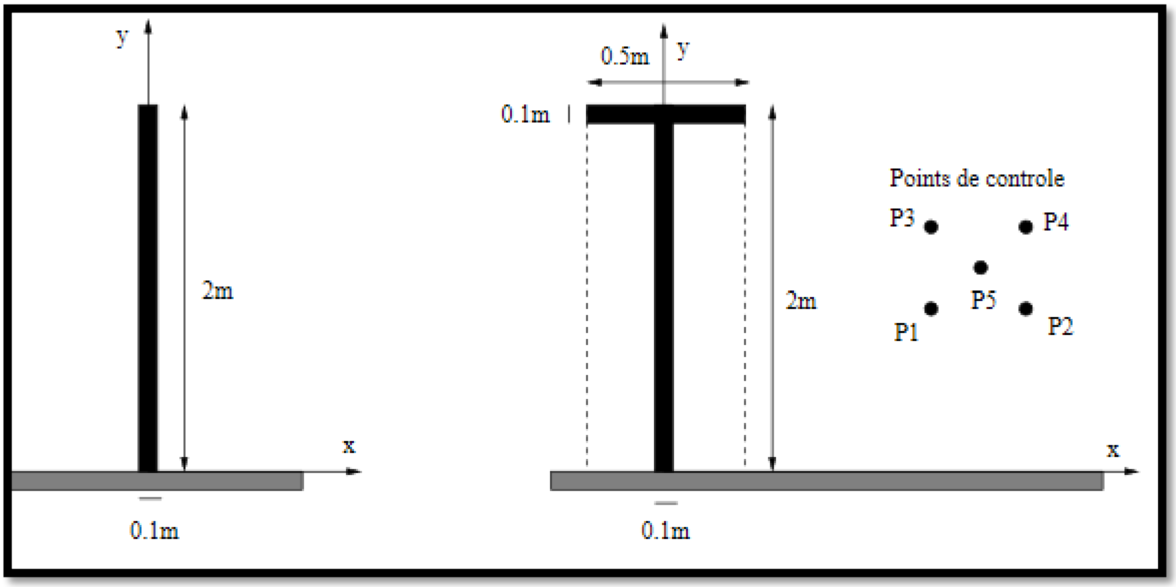
This part certainly will fall down!!! Question of gravity

Results Interpretation:

As we can see the practical realization of this type of wall is impossible. So, in this case, the optimization method turns out to be of little use because it offers an impractical model, for this, studies have been made on shapes which are a little close to the optimal one, such as for example a wall **like T or a straight wall.**

In the following, I make a comparison between a T wall and a straight wall.

The data from the experiment are presented below:



- The origin of the coordinate system is located on the ground in the center of the barrier.
- The sound source is placed at the point (-5m, 0) on the ground and radiates the pressure (i / 4) * H0 (Kr) in free field.
- The speed of sound is 340m / s.

We are interested in the sound level behind the barrier, by defining two control zones. The first zone, called zone 1, is a square of area 0.25m ^ 2, defined by the points in the following table:

Points	P1	P2	P3	P4	P5
X(m)	2	2,5	2	2,5	2,25
Y(m)	1	1	1,5	1,5	1,25

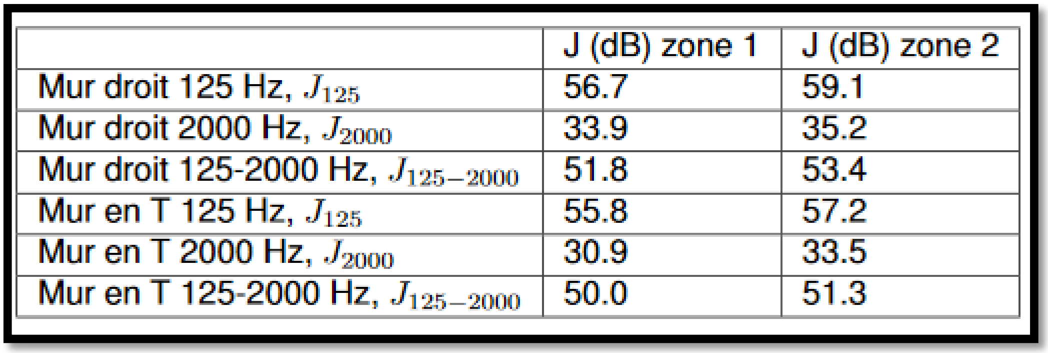
The second zone is larger and is defined by the points in the following table:

Points	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
X(m)	2	3	4	5	2	3	4	5	2	3
Y(m)	0	0	0	0	0.5	0.5	0.5	0.5	1	1
Points	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
X(m)	4	5	2	3	4	5	2	3	4	5
Y(m)	1	1	1.5	1.5	1.5	1.5	2	2	2	2

Note: why did we take two different zones?

- **It's just to improve results and be more specific.**

The results are presented in the following table:



	J (dB) zone 1	J (dB) zone 2
Mur droit 125 Hz, J_{125}	56.7	59.1
Mur droit 2000 Hz, J_{2000}	33.9	35.2
Mur droit 125-2000 Hz, $J_{125-2000}$	51.8	53.4
Mur en T 125 Hz, J_{125}	55.8	57.2
Mur en T 2000 Hz, J_{2000}	30.9	33.5
Mur en T 125-2000 Hz, $J_{125-2000}$	50.0	51.3

Note: DB (decibel) is the unit of sound power.

Results interpretation:

The **T** shape is a little more efficient than the **straight** shape by 1 to 3 dB depending on the frequencies. The average level in zone 2 is a little higher than in zone 1, which seems reasonable since more points are used for the calculation of the average.

Added value:

If we didn't try to find the optimal form of walls using optimization, we would have chosen the straight ones, but optimization has gave us an idea about the optimal shape, even if it was not practical but we was able to choose another shape that was close to It which is T wall, and after comparing it to the straight one, it turns out that T one was much more better.

Perspectives:

The subject of acoustic barriers is experiencing strong development. Research is intensifying to develop materials that absorb 100% of the noise emitted or materials on which sound waves are reflected several times and lose their energy. So we no longer focus on the shape of the wall but rather on the development of the chemistry of its components. Yes exactly, the trend is towards knowing how to act on chemical reactions and atoms to stimulate them to absorb the maximum sound energy.

Application in Morocco:

Noise barriers are very effective especially for people living in buildings located along railways or near airports, and there are thousands of people who suffer a lot from this kind of noise and witness powerful sound. This type of barrier does not exist in our country, and we do not deny that the acoustics sector in Morocco is not very developed compared to other countries in the world and moreover the regulation specifying the threshold of DB, to not out pass within buildings, only appeared in 2018.

Also, Moroccan acoustic design offices have only developed in Morocco in recent years. As an example the best known **Fotecma, Soctave, SY**-engineering ... and from what I learned during a contact with an employee at Soctave, the optimization methods used consist in the first place in the choice of materials to be used, and does not consist in solving the algorithms. In other words, they seek to optimize the cost and the sound transmitted by seeking for new materials that have the capacity to absorb and attenuate sound and at the same time that they are less expensive and easy to undertake without having to resort to algorithms. . And the trend today is towards organic and plant materials. In our country there are 3 categories of material insulation:

1. **Mineral fiber insulation**
2. **Insulators made from plant material**
3. **Synthetic insulators**

And each type has its advantages and disadvantages and it is up to the design office to choose according to the specifications, what is most suitable.

I think if they start building noise barriers, and have gone for straight walls, (which usually will be the case) then even by choosing the best insulating materials, they won't have the same results as they choose a T-wall with the same materials. What I mean is through optimization I was able to choose the shape of the wall that was closer to the optimal one and I was able to have decibel gain.

Finally, this model of barriers can take place in Morocco, the only obstacle will be the financial means because for example in France a 2m wall costs between 200 € and 300 € per linear meter depending on the material used, so it's a bit expensive. And another point, the use of optimization methods for acoustic work in Morocco must be integrated into all design offices and civil engineering companies to have the optimal distribution of sound.

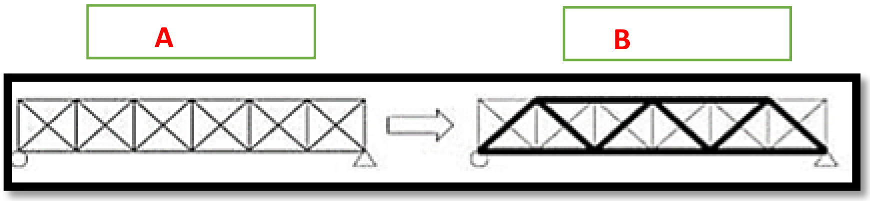
Optimization in architectural design

Choice justification:

This year, and during the material resistance sessions, we focused on the study of **lattices**. The teacher introduced us to two structures: Structure **A** and Structure **B**, **and asked us the question**, what is the difference between the two structures?

Most of the answers were as follows: “structure B cannot withstand large loads unlike structure A., because A contains more material. In other words, if we keep increasing the same load P applied to both structures simultaneously, structure B will collapse before structure A”.

The professor said: “You are all wrong, because the two structures are equivalent and withstand the same loads. The difference is that structure B is the optimized form of structure A. And besides, a structure that contains more material does not exactly mean that it resists better. "



I said to myself, for a very small beam, the optimization achieved a considerable gain in material, and as a result, an esthetically beautiful structure has resulted from it, **so what about giant structures? Are all the designs that exist in the world the result of optimization? Is it an integral part in the work of architects?** So many questions that pushed me to choose this topic to find out more about it.

Introduction to topologic optimization:

Much research has been carried out in the field of structural optimization. This technology, can be of great value, especially for the design of large and complex structures such as tall and very tall building structures. Recently, structural optimization has caught the attention of designers and practitioners of tall and very tall buildings.

The goal of structural optimization can be threefold:

- automate the complex design process
- optimize the performance of the structure
- Minimize the total cost of the structure.

The material, during the optimization process, is redistributed and parts that are not objectively necessary are removed. The result is a solid / empty structure, for which an objective function is minimized. The design area defined by the shape of a structure is divided into sub-regions, for which different materials are assigned.

During the design process, the material is moved, but only in the selected region. The proposed idea, was inspired by architectural designs such as multi-material facades of buildings. The efficiency of the topological optimization is determined by the appropriate choice of the numerical optimization algorithm. Among the very efficient heuristic methods used are those called **Cellular Automata.**

Cellular automata are a discrete mathematical idealization of a physical system. The technical implementation of cellular automata requires the decomposition of the design domain into a uniform network of cells. It is assumed that the interaction between cells only takes place in neighboring cells. The interaction is governed by simple local updating rules, based on heuristics or physical laws. Numerical studies show that this method can be an interesting alternative to traditional gradient-based algorithms.

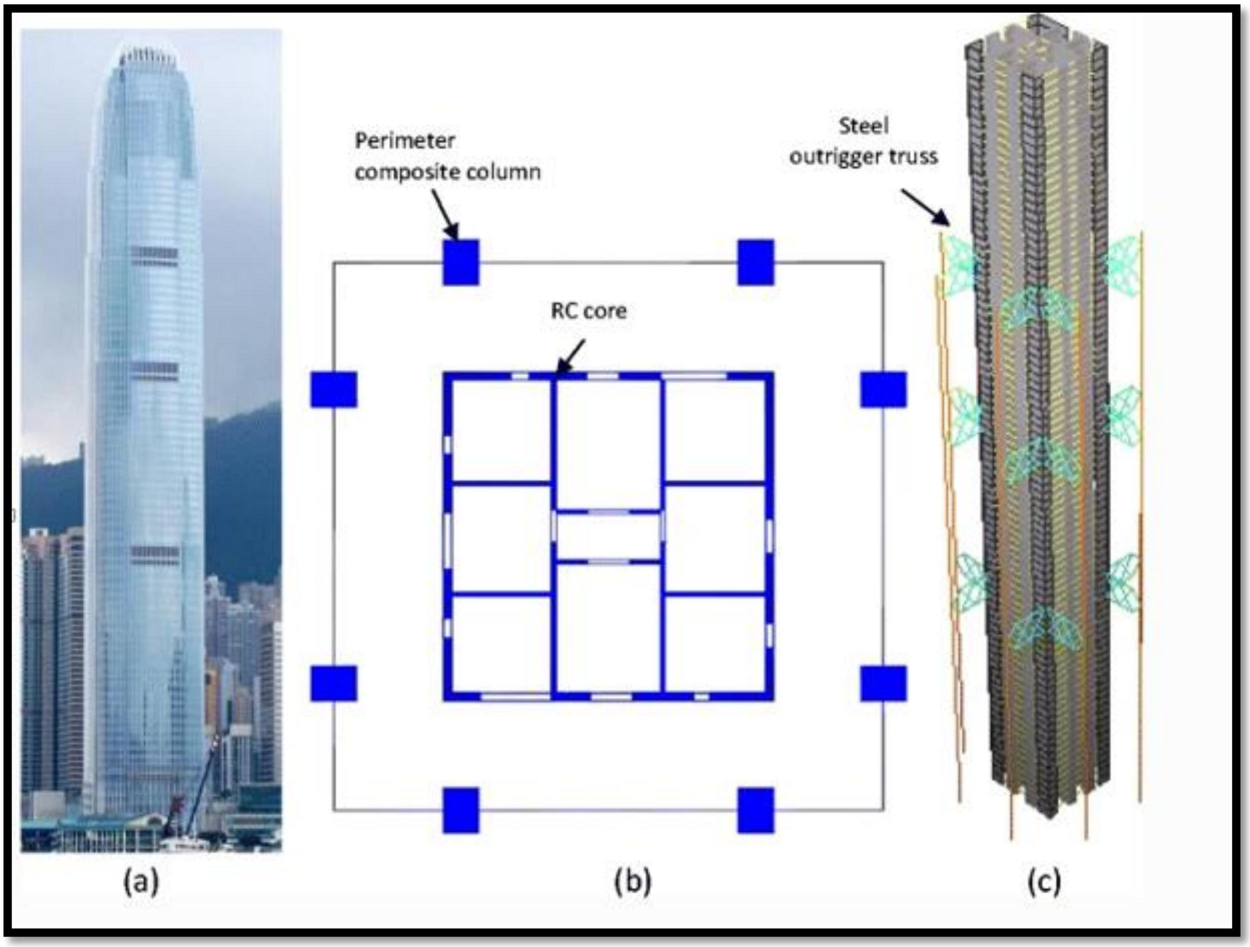
Example of a skyscraper-Hong Kong:

Here is an example that shows the minimum cost optimization of the North East Tower of Hong Kong Station, an 88 floors, 420m high commercial building.

The tower side support system consists of an RC core and eight composite perimeter mega columns. The core and columns are connected at three levels by steel stabilizer trusses. The critical cases of side loading were found to be related to the wind load, which was calculated using the results of wind tunnel tests in accordance with the Hong Kong building code. The optimization goal is to minimize the cost of the material based on lateral drift and practical limb size limitations. The optimality criteria (OC) method is used for optimization with the following objective function:

$$\boxed{W = \sum_{i=1}^{N_s} (w_{si} * A_i) + \sum_{i=N_s+1}^{N} (w_{ci} * B_i D_i)}$$

Where N is the total number of structural members, Ns is the number of steel members in the structure, wsi and Ai are the cost coefficient and the cross section of the steel member i, respectively. The number of concrete elements is N - Ns. The terms wci, Bi and Di are respectively the cost coefficient and the width and depth of the cross section of the concrete element i. wsi and wci include the floor area costs associated with the column (tributary zone). The optimization method resulted in an increase in the size of the steel sections in the stabilizer trusses and composite perimeter columns (mainly in the upper floors), and in a reduction in the size of the central walls and columns. While the enlargement of the steel sections increased the material cost by 8.1% compared to the non-optimized solution, the reduction of the concrete section for core walls and mega columns increased the floor areas. In particular on the more valuable upper levels, which led to a total cost saving of 9.1% compared to a non-optimized solution.



Added value:

Before optimization:

Waste of energy, time, materials

→

After optimization

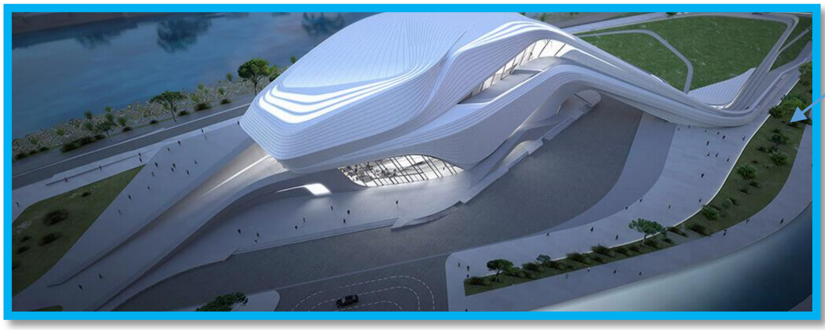
Energy gain, time gain, material gain

Application in Morocco:

Question for you: Have you ever heard of **Zaha Hadid**? Does this name remind you of anything?

If you have ever passed near the construction site of **the Grand Theater in Rabat**, you have undoubtedly noticed her name on the site panel as the responsible architect.

Zaha hadid is an architect well known for her amazing designs. In collaboration with her team, she applies advanced **optimization** techniques in the design of her multiple structures.



The great theater in Rabat was designed by **Zaha hadid** and its splendid form was the subject of an optimization study based on algorithms solved by powerful software.

The optimization in moroccan architecture ?

In Morocco, architects draw up plans for the construction concerned and deliver them to the design office to calculate the reinforced concrete…. And then comes the execution stage. And, in general, civil engineers try to act on the reinforcement or the addition of admixtures to the concrete to optimize the cost but they do not work in collaboration with the architects to optimize the overall shape of the structure. And that's the difference between the case of Morocco and the architect Zaha Hadid.

Moreover, optimization is not taught at all in the great Moroccan schools of architecture like **ENA** (national school of architecture), and therefore most architects are limited to their imaginations to develop the forms of construction and ignore the optimization methods that can help to design new structures that are even more beautiful by optimizing material and cost and also energy.

Therefore, **I think** that Moroccan architects must start to be interested in optimization algorithms and document themselves as much as possible so that they can collaborate with civil engineers in order to generate well-designed structures. I also specify that the Moroccan design offices must have as an integral part in the development of their projects, methods and software for optimizing the results of each stage of construction, and of course, include this in the school programs of future engineering students.

Also, a civil engineer today is supposed to master not only the calculation of his structures but also to be able to manipulate the software and to have an idea on the optimization methods to be able to generate profit for his company

Bioclimatic Optimization

Choice justification:

Feeling comfortable at home is a priority in my life. And to achieve this, it is essential that the environment in which I live meets certain criteria. **I say for example sufficient solar radiation that manages to penetrate my house.**

If I had a house in the companion very far from the built-up areas, and which had windows in all the facades, that would have been perfect because I will have the sun all day but unfortunately we live in cities, in neighborhoods or housing estates which causes a major problem, especially for buildings with a north facade.

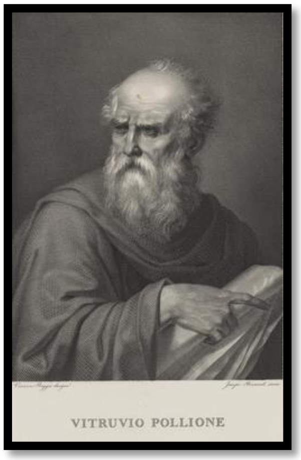
In this context, and even before starting the optimization courses this year, I take a paper from time to time and I try to draw our neighborhood on it differently, so that all the inhabitants had their share of the solar radiation, but, it has always been difficult for me.

With my initiation to optimization courses, I became aware of the existence of several types of algorithms that allow solving the most complex optimization problems and I said to myself that this can be used to obtain the shape of the most optimal neighborhood.

And this is called **bioclimatic design,** which consists not only in the orientation of buildings to take advantage of solar gains but also in several other parameters such as thermal and acoustic comfort, but in this work I am limited to the first criterion: **take advantage of the maximum amount of solar radiation in the urban context.**

Historical overview:

Roman architect.



The work of **Vitruvius** has had an important influence through the centuries, especially in the orientation of buildings and the arrangement of rooms in relation to solar radiation.

The method used:

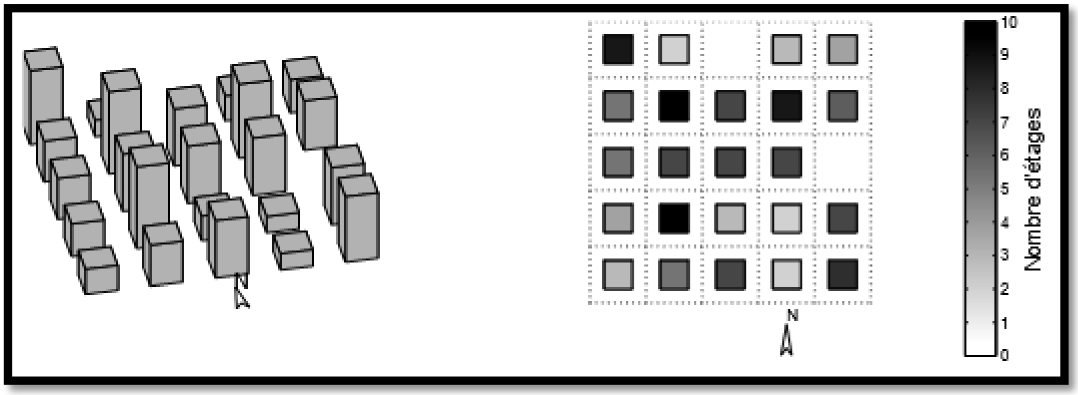
The optimization method used is: the genetic algorithm explained previously.

Calculation:

Calculation assumptions :

- The districts will be represented by a set of blocks forming piles, and can represent the distribution of floors in towers.
- The buildings are separated from each other.
- Buildings receive solar radiation through their envelope.
- Reflections are not taken into account.

Here is an example of a block representation:



Calculation of solar radiation :

It is essential to note that by solar radiation we mean:

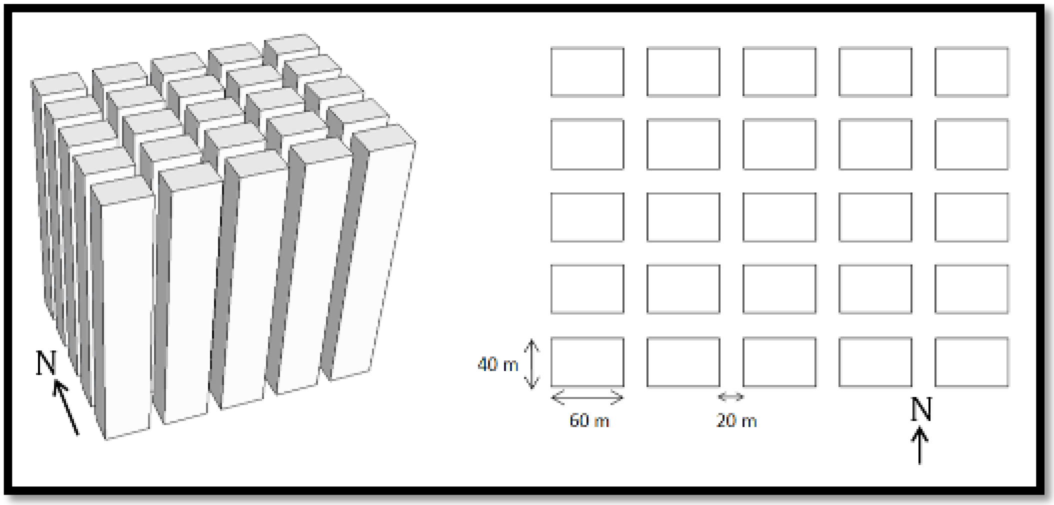
- Direct radiation in clear skies;
- The sky view factor;
- Direct and diffuse radiation based on the use of meteorological data.

In order to calculate these different quantities, intermediate steps are necessary:

First, the position of the sun must be calculated. This makes it possible to determine the solar radiation in clear skies. Next, the sky is broken down into a set of tiles, which are used in the calculation of sky view factors. Finally, solar radiation is distributed over the celestial vault and accumulated over a period of time. These cumulative skies, combined with the sky view factors, give an estimate of direct and diffuse solar radiation.

Calculation data for our studied example:

- The example consists of a set of buildings located in Basel (Swiss).
- We have 25 buildings distributed on a grid of 5x5 rectangular locations which represent a theoretical district. Each building is defined by its number of floors, between 0 and 123.



Objectif function:

It is about the annual global radiation, in order to obtain the most optimal shape of the quarter throughout the year regardless of the position of the earth in its orbit around the sun.

$$f(X) = \int_{T_1}^{T_2} \sum_{i=1}^{N_{faces}} cos(\theta_i(t))\, I_{bn}(t) \int_{S_i} Vis(y,t)dydt$$

With :

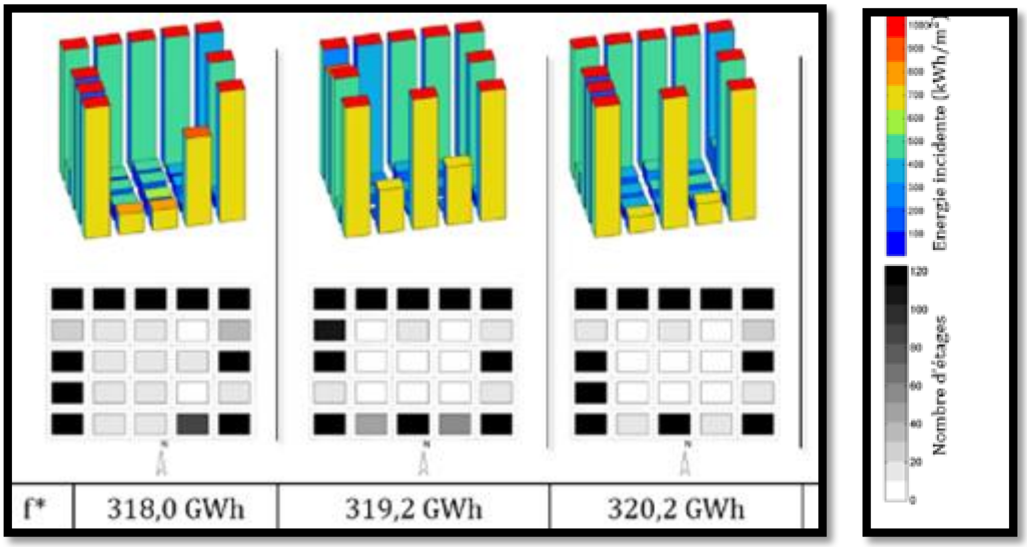
Ibn(t) : normal direct irradiance at time t.

Teta I (t): the angle of incidence of the sun's rays on the surface Si.

Vis(y,t): a visibility function equal to 1 if the point ”y” sees the sun at time t, 0 if not.

The optimization program was developed in MATLAB.

Results :



Gwh: Gega watt hour, power unit.

Important note:

- It should be noted, that here the optimization is used to study the optimal shapes, based only on solar radiation, but in reality other parameters like heating have to be considered. In other words, a solution can be optimal in terms of solar radiation but not in terms of heating.
- These results are only related to Basel. Whenever we change the **latitude** results change too.

Interpretation of results:

In the figure above, we see the three forms of the neighborhood which have the maximum objective function.

They correspond to the shape of the neighborhood which benefits from the maximum of solar radiation.

The **third figure** is the one with the maximum objective function (320 Gwh), which means it is the most optimal form in this region: Basel.

We notice that the buildings in the middle have been almost eliminated, or contain only one floor. To take advantage of the remaining space, we can build gardens or houses in the form of **Domespace** that we will see later.

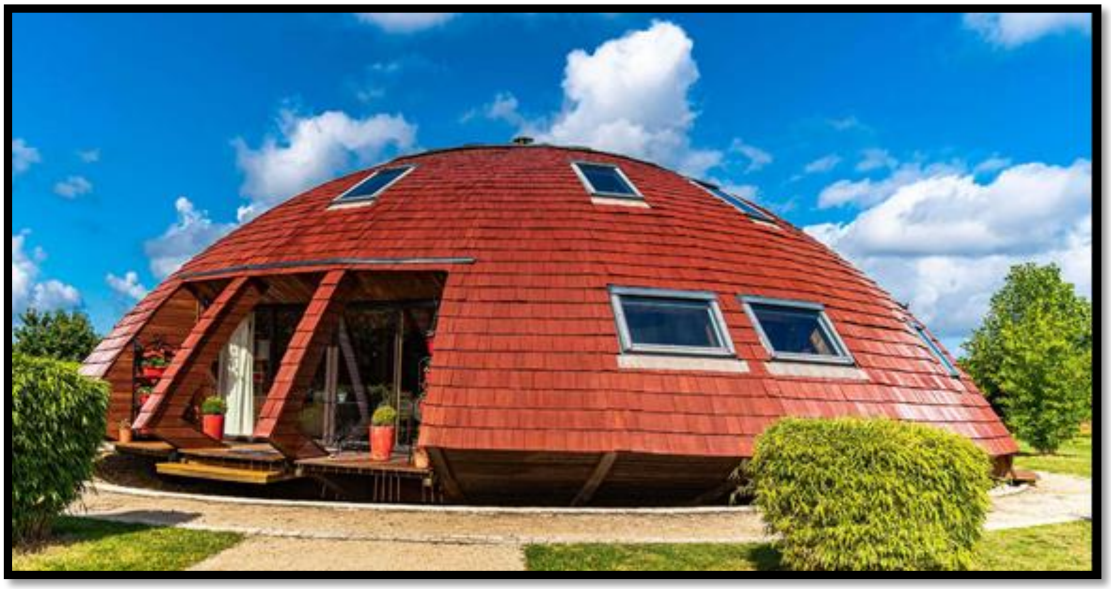
Added value:

With the optimization we found the shape of the neighborhood where all the inhabitants have their share of the sun unlike the shape of the neighborhood at the start (before optimization) that was really a bad choice because it does not present an optimal distribution of natural solar gains but unfortunately it is the most common form in all countries of the world, and this is because of the drastic increase in the population which leads to designing buildings just to meet the needs of the habitat without taking into account the living conditions inside.

New perspectives:

The Domespace:

This is a house that **rotates with the sun** to take advantage of the maximum solar gain.



Application in Morocco:

What if we want to build the Domespaces in Morocco?

→ Price ?

→ means ?

Noting that the Domespace is a single house, then it is not a solution for buildings with multiple apartments where multiple families live.

➡ It is for this reason that I became interested in subdivisions where most land owners build a detached house of R + 2 in general.

Calculation :

- Let’s consider a land area of 100m2 (10m * 10m)
- The price per m ^ 2 of living space in a Domespace is estimated in France at 2025 € which means 20250 Dhs.

➡ So the construction of a 10m diameter Domespace is estimated at (pi * (5 ^ 2)) *2,025 € = 159,043€ = **1,590,434 dhs**

- The construction of an R + 2 in Morocco on the same land is estimated at **690,000 dhs.**

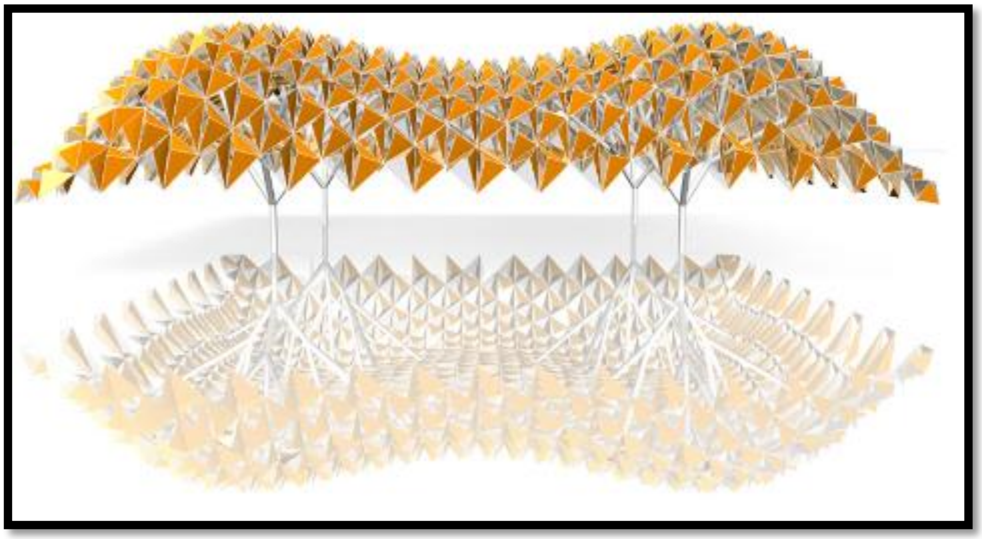
That’s a big difference

Analysis:

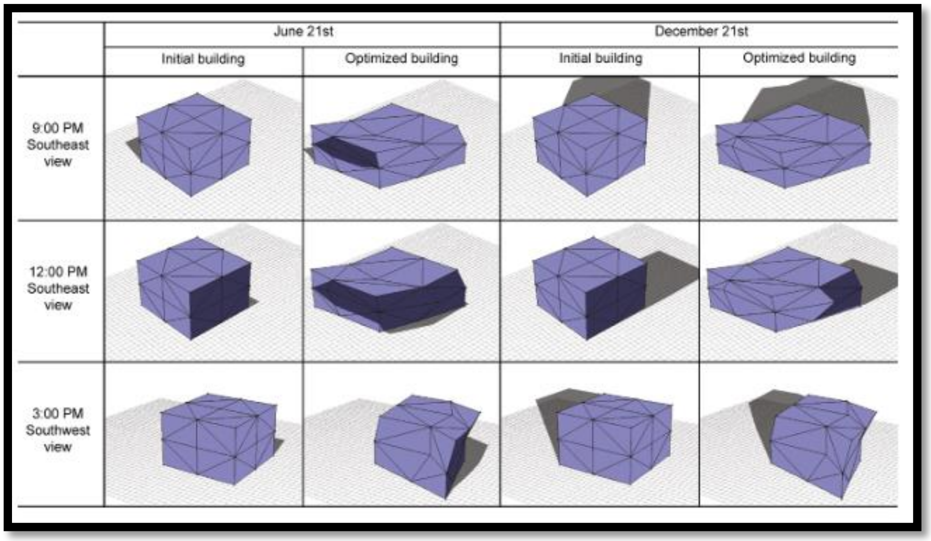
The price is really too expensive compared to a classic house, but you will have sun all day long, and it is really essential and you will not think about the price anymore if you are aware of the benefits of the sun which is the main source of vitamin D, essential for the proper functioning of the organism and the consolidation of bones and teeth. It also acts positively on our morale by stimulating well-being hormones and providing a healthy glow.

In my opinion, I think that this kind of house can see the light of day in Morocco when Moroccans start to adopt minimalism in their house building habits. In other words, no longer focusing on the construction of R + 2 and R + 3 just to have a lot of space but to look towards healthy habitats.

Sometimes we find complex shapes, like the one shown in the following figure:



We can also work on the morphology of the roofs of buildings to obtain the best natural light in a large rectangular room:



Conclusion :

Optimization has become a substantial tool to consider in the development of all current projects. Civil engineering is an area that requires these kinds of methods in all stages of project execution, from concept design to construction.

We have clearly seen in all the examples cited above how it contributes to the minimization of the use of resources, to the reduction of the energy used and therefore to the conservation of our natural heritage: planet earth.

I see that, faced with the environmental challenges facing the planet, it is time for all the countries of the world to think about integrating these optimization approaches into their economic systems because we are all concerned by the protection of our environment and because we are the primarily responsible for all current natural disasters.

And I say that Morocco needs to strengthen these efforts in terms of scientific and technological research to train high-performance and competent executives in these fields and thus be able to adopt these methods of optimization in all these projects. All the methods mentioned in this report can be approached by Morocco, it just needs to get into this field and develop all the knowledge necessary to master it well.

References:

https://ch.mathworks.com/fr/search.html?c%5B%5D=entire_site&q=algorithme%20%C3%A9volutionniste&page=1

https://fr.wikipedia.org/wiki/M%C3%A9taheuristique#Liste_de_m%C3%A9taheuristiques

https://www.travauxapart.fr/guides/prix-dun-mur-anti-bruit

https://construction-maison.ooreka.fr/astuce/voir/574487/maison-tournante

https://www.researchgate.net/publication/269122464_Optimization_in_Structural_Analysis_and_Design
https://hal.archives-ouvertes.fr/hal-00362979/file/doc00000638.pdf

https://tel.archives-ouvertes.fr/tel-01095637/document

https://redshift.autodesk.fr/theatre-rabat/

https://tel.archives-ouvertes.fr/tel-01095637/document

https://www.researchgate.net/publication/269122464_Optimization_in_Structural_Analysis_and_Design
file:///C:/Users/Naima/AppData/Local/Temp/9.pdf

https://domespace.wixsite.com/domespace

The end.

Thank you for reading.